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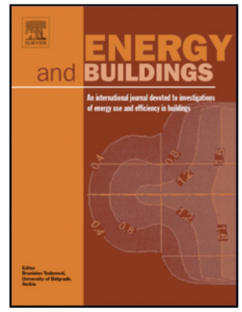

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Authors: Arindam Dutta, Akash Samanta, Subhasis Neogi

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Influence of Orientation and the Impact of External Window Shading on Building Thermal Performance in Tropical Climate

Arindam Dutta[1], Akash Samanta[1], Subhasis Neogi[2]*
[1]Indian Institute of Social Welfare and Business Management, Kolkata, India
[2]School of Energy Studies, Jadavpur University, Kolkata, India

*Corresponding Author's Email- arindamdutta190@hotmail.com

Highlights:

- Solar radiation model was developed through FORTRAN 77 based on available radiation model.
- Total heat gain inside a building through different oriented windows was analysed.
- South oriented window is responsible for maximum amount of heat gain.
- Energy consumption of building was estimated through validated TRNSYS model
- 14.9% energy savings can be achieved during peak cooling season with dynamic shading device.

Abstract

Energy saving in buildings is a high-priority in developed countries as buildings are responsible for a substantial part of the energy consumption. Typically heating, cooling and artificial ventilation systems of a building are major consumer of energy. A validated Fortran 77 compiler program has been used to elaborate the influence of building orientation on building energy consumption. The amount of heat influx through windows on different oriented vertical walls for various direction has been compared and it has been found that heat gain through south oriented windows is maximum followed by East, West and North bound windows in a tropical climate of northern hemisphere. An experimentally designed, Programmable Logic Controller based movable exterior window shading device linked with sun path has been introduced through a validated TRNSYS building model to show the reduction in cooling load of a hospital building in tropical climate. The simulation study shows that maximum energy savings can be achieved in the month of June i.e. 14.9% and average energy savings is 9.8% annually by movable exterior window shading for a building in tropical climate. Through an economic analysis it has been established that the proposed exterior shading device is financially viable and the payback comes within 6 months. This study is useful for professionals who are responsible for decision-making during the design phase of energy-efficient buildings and can show a path for sustainable building design.

Keywords: *Solar radiation model, Dynamic shading device, Simulation, Autodesk Ecotect, Energy savings.*

Nomenclature

E_{sh} = Solar direct irradiance on horizontal surface
E_0= Extraterrestrial radiation
a=Mean extinction coefficient of radiation

m= Optical air mass
T_v=Turbidity factor
γ_s= Solar azimuth angle [Rad]

E_{dh}= Sky or diffuse irradiance on horizontal surface
q_a^m=Factor for absorption through the atmosphere
I_b= beam radiation on horizontal surface [W/m^2]
H_{b_c}= Monthly-averaged potential daily clear-sky beam irradiation on a horizontal surface
S_c= The monthly-averaged day length for the sun position above a critical solar elevation angle
T_{min}= Minimum ambient temperature
q= Instantaneous heat gain in Watt
A= Area of surface in m^2
α= absorptance of surface for solar radiation
I_t= total solar radiation incident on surface in W/m^2
h_0= coefficient of heat transfer by long-wave radiation and convection at outer surface, W/m^2.K
U_o= Overall coefficient of heat transfer (U-factor) in W/m^2-°K
t_{in}=interior air temperature in ºC,
H= Daily global radiation
H_{clear}= Monthly-averaged daily clear-sky radiation on horizontal surface
α= Absorptance
S= the monthly-averaged time fraction of bright sunshine (0≤S≤1)
H_o=Extraterrestrial radiation
a, b= empirical constants
I_d= Diffuse radiation on horizontal surface [W/m^2]
I_o= apparent extraterrestrial radiation

H_b= Monthly-averaged daily beam irradiation on a horizontal surface
s= The monthly-averaged sunshine duration

T_{max}= Maximum ambient temperature

C_w= the mean of the total cloud cover of daytime observations

f_{clear}= time fraction of clear sky
t_0= outdoor air temperature in °C,
t_s= surface temperature in °C,
ε = hemispherical emittance of surface,
ΔR = difference between long-wave radiation on surface from sky and surroundings and radiation emitted by blackbody at out-door air temperature, W/m^2
t_{out}= exterior air temperature in ºC,
$SHGC_t$= Overall solar heat gain coefficient, non-dimensional
A_{pf}= Total projected area of fenestration, m^2

1. Introduction

India is poised with a growth rate of 8–10 per cent in the building sector. In the building sector, commercial buildings space accounts for 33 percent [1]. According to UNDP and Climate Work Foundation, the annual energy consumption for the commercial buildings in

India is in excess of 200 kWh per square meter per year [2, 3]. This has led the Government of India to include commercial building as 'designated consumers' under the Energy Conservation Act (2001) [4]. It has also been estimated by Srinivas [1] that energy conservation interventions in new buildings as well as existing buildings in India can reduce 20–50 per cent energy consumption by incorporating appropriate measures like building envelope designing based on solar radiation modelling, lighting designing using daylight simulation and measures to reduce the load of heating ventilation & air-conditioning (HVAC) systems. Ellis et al. [5] have identified that HVAC system is responsible for more than 30% of building total energy consumption and according to Hsieh et al. [6] solar irradiation through fenestration, heat from artificial lighting, latent heat from moisture, ventilation and infiltration are the major influencing variable of the cooling load of a HVAC system in building. The estimation of solar radiation incident on building envelops is always a paramount importance to various researchers for analyzing the preference of building envelops and cooling load due to heat gain from solar radiation. Grynning et al. [7] revealed that among all the building envelops windows are responsible for maximum amount of heat gain/loss inside the building i.e. almost 45% whereas roof, wall and floor are responsible for 8%, 8% and 9% respectively. It is a fact that solar radiation directly incident on a glass surface is transmitted within the building to the extent of 88% [8]. Not only the type of fenestration but building orientation also plays an important factor for heat gain/loss in building envelope. Again the heat gain depends upon how much total solar radiation irradiated on various surface of building depending on building orientation [21, 22]. From the literature review it is evident that window is the most vital part of a building to minimize heat gain/loss. The important thing to know is in which orientation heat gain/loss will maximum and what measures should be applied to reduce heat gain/loss without affecting the daylight harvesting through windows.

According to The Energy Resource Institution (TERI) [23] south envelops requires proper shading solution to block unwanted solar heat gain for an Indian building as it receives maximum amount of solar irradiation. Taleb [24] identified that North side is the more comfortable zone of a building due to less amount of direct solar radiation. When we think for shading as a solution it comes to our mind that whether we go for internal shading or external shading. Kim et al. [25] have conducted a series of simulations by an energy analysis program IES VE and revealed that the external shading device promises the most efficient performance compared to internal shading devices. It is evident from literature review that exterior shading of building envelops, especially window shading is one of the appropriate strategy to control unwanted ingress of heat for a building as windows are responsible for maximum amount of heat gain into a building. At the same time the proper place and an economic analysis also required to check the technical and financial viability of shading device. Though various researchers [26-28] have already developed and implemented different types (both manual and automatic) of external as well as internal shading devices for windows but they are not linked with sun path. If the external shading devices are not linked with sun path then it will unnecessary block the daylight through window and thereby increase the energy consumption through artificial lighting. In this study heat gain through windows in different direction has been estimated through a FORTRAN 77 compiler program. The proposed movable window shading device has been tested through validated TRNSYS building model to examine its potential to reduce heat gain for a hospital building in tropical climate. An economic analysis has also been done to check the financial viability of such exterior shading device.

2. Solar irradiation on Building Surfaces

2.1. Models and Calculations

Modelling of thermal performance of a building depends on the amount of solar radiation arriving at the building surface. The amount of heat flow within building interior is important for understanding and predicting its thermal behaviours. The radiation incident on tilted surface comprises of mainly three components; beam, diffuse and solar radiation reflected from the ground. Various methodologies [9-20] have been invented by researchers to quantify the amount of solar radiation on tilted plane as depicted in Table1.

The only difference among the models appears in the assessment of sky-diffuse component. The estimation models can be broadly classified in isotropic [12, 30] and anisotropic [20, 31, 32] based on the assumptions made for sky-diffuse radiation. According to the isotropic models the intensity of diffuse sky radiation is uniform over the sky dome. Pandey et al. [33] have compared six solar radiation models (Badescu, Circumsolar, Skartveit and Olseth, Hay, Klucher and Liu) and found that all these models adopted the more or less same methodology for estimating solar irradiation on tilted surface in tropical climatic condition like India. They have also found that most of the models showed good level of accuracy, the Root Mean Square Errors (%RMSE) value varies from 3.45% to 24.15% except for Badescu and Circumsolar model which predict worse results.

2.2. Validation of solar radiation program developed through FORTRAN

The isotropic radiation model as derived by Liu and Jordan [12] was considered in this study to estimate the global radiation (W/m^2) on any tilted plane. Though if hourly Anisotropic index is available then Hay and Davies model [20] can also be applicable here. The solar radiation program algorithm was coded in FORTRAN77 compiler. Horizontal global & diffuse and vertical global solar radiation were recorded by a monitoring system located on the roof of a four-storied School of Energy Studies building at the Jadavpur University, Kolkata in India. One pyranometer was placed on the fixed horizontal plane of the platform to measure horizontal radiation and the other on the tilted plane having tilt angle 90° with the horizontal to measure the radiation on vertical plane as shown in Fig.1. Both the platforms of the experimental setup can be moved in desired position as required. The vertical plane of the platform was set along the window plane of the room. The data collection was carried out for a continuous 24 hours cycle for one year. Pyranometer readings were scanned in 1 minute interval and recorded by an online data acquisition system as shown in Fig.2. The online data accusation system consisted of a programmable Data-logger (model: HP 34970A). Standard computer serial port i.e. RS232 was used to interface the data accusation system with a portable computer for online transfer of solar radiation data.

The total & diffuse radiation on horizontal plane was measured to compute the total radiation at any inclined surface by FORTRAN 77 compiler program. Solar radiation data in 1 minute interval was considered to calculate the instantaneous value of solar radiation on any plane. The solar radiation program then validated by the actual set of radiation data obtained from pyranometer which is mounted on the tilted plane as shown in Fig.1. Solar compiler program has been validated with experimental data through statistical indicators i.e. the Mean Bias Error (%MBE) and Root Means Square Error (%RMSE) as previously applied by other researchers [33,34]. The experimental data has been collected collected with 1minute interval from June 2010 to May 2011. We found that the percentage MBE and RMSE between the simulated and measured values of vertical radiation varies from -4.9% to +5.1 % for MBE and -2.1 to +6.1% for RMSE respectively. The MBE and RMSE values indicate that the solar radiation simulation program provides close agreement with the measurements.

2.3. Calculation of incident solar radiation falling on various oriented envelop of building

The developed solar radiation program can be used to simulate solar radiation at any place with known latitude and longitude. For our present need the solar radiation program was simulated for Kolkata region with latitude 22.53°N and longitude 88.33°E as the reference building is located in Kolkata. Standard longitude was taken as 81.86°E. The program was simulated for a whole year at different surface azimuth angles such as $\gamma = 0°$, $\gamma = +90°$, $\gamma = -90°$ and $\gamma = 180°$ with surface tilt(β) equal to 90° to quantify the solar irradiation on window pane. Table2 illustrates the patterns of incident solar radiation on vertical plane for 15th day of June at different orientation for window pane.

3. Heat gain inside a building through window glazing

ASHRAE [29] provided detail information on the theoretical calculation to quantify heat transfer through building envelops. When solar radiation is incident on the outer glazing surface of window, the heat transfer takes place from the outside atmosphere to the inside room through the window glazing by all three kinds of heat transfer, i.e. conduction, convection and radiation.

As per ASHRAE 2001 [29] for a sunlit exterior surface of a building the heat flux per unit surface can be represented as

$$\frac{q}{A} = \alpha I_t + h_0(t_0 - t_s) - \varepsilon\Delta R \qquad (1)$$

Heat transported by conduction, long-wave radiation and convection is in general related to the total U-value of the window. Solar short-wave radiation is also a major contributor to the heat flows and is related to the SHGC of the window glass.

To quantify the heat gain/loss through a fenestration product or Window glass (assuming no humidity difference and excluding air infiltration) the expression can be expressed as [29]

$$q = U_o * A_{pf}(t_{out} - t_{in}) + (SHGC_t * A_{pf} * I_t) \qquad (2)$$

From eqn. 2, the Relative Heat Gain (RHG) per unit projected area of fenestration can easily be calculated by integrating the incident total irradiance throughout the day from sunrise to sunset. The equation of Relative Heat Gain (RHG) can be expressed as,

$$RHG = \int_{t=sunrise}^{t=Sunset} (I_t) * SHGC + U_o(t_{out} - t_{in}) \tag{3}$$

Here the dry bulb temperature of Kolkata throughout the year was considered as exterior temperature [36] and inside air temperature was fixed at 25^{o}C [37] during simulation. The temperature distribution over the entire glazing due to the heat transfer by conduction was considered as uniform as suggested by Farina et al. [37]. Then the previously validated FORTRAN 77 solar radiation program was modified based on eqn. 3 to estimate the Relative Heat Gain (RHG) for a building in tropical climate like Kolkata. A reference building was considered to examine the impact of orientation upon the relative heat gain. Further the impact of an experimentally designed movable exterior window shading device upon the building cooling load was also analysed with the help of TRNSYS17 building model

3.1. Heat gain through different oriented windows using FORTRAN

To find the Relative Heat Gain (RHG) through windows oriented in different direction of the building. A normal 6 mm single clear glass (U=5.7W/m^2, SHGC=0.8) was selected in the FORTRAN program. The Total Relative Heat Gain per unit projected area into the building through window at different oriented panes has been shown in Fig.3. For the analysis two months i.e. January and June were selected from two extreme weather conditions, winter and summer respectively.

From the Fig.3 it is evident that the Relative Heat Gain per unit projected area was highest through south oriented windows and lowest through Northern windows. We found that heat gain is more 96%, 38% and 20% respectively for south bound window, east and west bound with respect to northern window for a typical summer month. Here actual recorded solar radiation data of all the days including sunlit and cloud cover day of a particular month has been considered for the study i.e. the simulation program is valid for an anisotropic condition also. The result shows that southern window receives maximum radiation and therefore maximum heat gain as depicted in Table2 and Fig.3 respectively. This result revalidates the conclusion of other researchers [23, 24].

4. Case Study and Building modelling simulation

4.1. Characteristics of the case building

For base-case simulation a 10 storied commercial hospital building, located in Kolkata, India was considered in this study. It covers a gross floor area of approx 20,431 m^2 comprises general wards, special wards, doctors chamber, outdoor, OTs, laboratory, library, guest house, kitchens etc. A detailed baseline survey and energy audit of the facility were carried out to collect various baseline information including building electrical, mechanical equipment schedule, energy consumption, architectural drawing, occupancy schedule etc.

In the facility the floor to floor height is 3.96m and floor to ceiling height is 2.74m. The concrete roof surface excluding Plaster and Insulation has a thickness of 0.1524 m. The vertical exterior walls are multilayer type and bituminous felt is used in roof as well as in the exterior walls for water proofing purpose. The interior walls are predominantly made of cement mortar. The thickness of interior wall is 0.025m. The exterior building surface was painted in off white colour during the visit to this facility. The composition of different walls and their respective U-Values have been shown in Table2.

Revolving glass doors are installed in each floor of building on the North and West side only. All windows are single glazed with 6 mm thick clear glass fitted in aluminium frames. The zone wise area distribution and dimensions of doors & windows are depicted in Table3.

4.2. Base-case modelling simulation with TRNSYS17

TRNSYS 17 has been applied to build the base case hospital building model. Monitored meteorological file was collected from the US department energy for the location of the case building in compatible format i.e. TMY2 for TRNSYS17. The 3-D layout of the building was developed in Trnsys3d plugin of Google Sketchup based on the building architectural design. The various adjacent zones were also specifically defined in the Google Sketchup. The envelope of the house represents the main path for energy transmission between building and its environment. All the building details including 3D-layout envelop properties, boundary conditions, occupancy schedule, lighting schedule, leakage, infiltration, various internal heat gains along with some standard values from the guideline of ASHRAE 90.1 were trained into the base case simulation model. The TRNS-build program (multizone building, Type 56) was used to find the detailed building construction information in the model. As the neighbourhood of the building complex is almost vacant; hence, there is no external shading effect of other high rise buildings on the building under study. Thus the factor covering of building has not been taken into account in the Type56 module. The building Floor plan and 3-D model of the baseline model have been shown in Fig.5.

4.3. Validation of TRNSYS Simulation Model

The usefulness of any simulation model depends in part on the accuracy and reliability of its output. Schranzhofer et al. [38] and Dutta et al. [39] applied statistical analysis with the measure and simulated data to validate the TRNSYS generated simulation model. Bou-Saada and Haberl [40] proposed the adoption of standardized statistical indices i.e. Mean Absolute Error (MAE) and Root Mean Square Error (RMSE) which better represent the performance of a model. Here we have also adopted MAE and RMSE tools to validate the TRNSYS17 generated model with the actual monthly energy consumption of the reference building.

$$\%MAE = \frac{\sum(E_{sim}-E_{act})}{\sum E_{act}} \; X \; 100 \tag{4}$$

$$\%\,RMSE = \sqrt{\frac{\sum_1^n (E_{sim}-E_{act})^2}{n}} \; X \; \frac{100 \; X \; n}{\sum_1^n E_{act}} \tag{5}$$

where n is the number of data pairs; E_{sim} and E_{act} are simulated energy consumption and actual metered energy consumption in kWh of the case building.

We found from the statistical analysis that the Mean Absolute Error (%MAE) varies from -14.5% to 26.9% and Root Mean Square Errors (% RMSE) value varies from 3.9% to 26.9%

as depicted in Fig. 5. Hence it can be easily stated TRNSYS17 generated model provides close agreement with the actual building energy consumptions.

4.4. Solar radiation simulation using Autodesk-Ecotect for justification of orientation

Solar radiation simulation using Autodesk Ecotect [41, 42] was also carried out for base building to revalidate the finding of solar irradiation in different orientation. Ecotect is a comprehensive building and environment modelling tool which are widely used for the efficient visualization of climatic conditions such as diurnal temperatures, prevailing wind directions, available direct and diffuse solar radiation and sun path etc. Architectural drawing of base building, field information and weather data of Kolkata into the Ecotect simulation tool to estimate the amount of solar radiation received by different oriented envelops of the case building. Though the tool does not forecast the exact amount of solar irradiation due to the subjectivity of the exact dimensions and location of surrounding objects such as trees, neighbouring buildings etc [43], however the analysis is helpful to find which part of the building envelope require a good shading solution to get minimum ingress of unwanted heat without affecting the optimum utilization of daylight. In our case building as there is no objects nearby so the AutoDesk Ecotect is perfectly useful. The solid block was modelled by Ecotect based on the architectural drawing of the building. The simulation for Average Daily Incident Solar Radiation has been done for the period 01st Jan to 31st Dec from 0800 hrs to 1800 hrs on all days. The Sun movement and the radiation profile of South & North oriented building envelops on the 15th June were depicted in Fig.7 as a sample. The various colours indicate the intensity of solar radiation in various portions.

It was clearly revealed from Fig.7 that the South bound building envelops receives highest amount of solar radiation and North bound envelop receives lowest. This also reconfirms our finding that application of effective shading device on the south oriented windows can effectively reduce the heat gain of building envelope.

5. Optimal introduction of dynamic automated external shading

It has been already proved that **t**he shading devices on windows with controls have a major effect on energy consumption of the building due to solar heat gain, heat transmission, and infiltration [26]. The basic function of a shading device is to intercept the sun's rays before reaching the building interior during the cooling and heating seasons. Various research studies have also showed that the optimum shading system depends on shading type, location, and weather conditions [25, 29]. We have developed an effective movable window shading device [39] especially designed for Indian climate condition. The movable shading device is consisting of front mounted roller Venetian blinds, Programmable Logic Controller (PLC), stepper motor and other accessories. The PLC ladder logic was designed and tested using GE, Factory Automation Numerical Control (FANUC) PLC. Datta [44] has found that shading factor varies with the time of day and is different for different locations. Therefore an optimum shading schedule for the location of a case building is most important. An optimum shading schedule for the location nearest to the case building has been designed based on the sun path of that location. The shading schedule and PLC automated movable shading device has been depicted in Fig. 8.

As seen from Table 2 & Figs.3&7, the solar irradiation and thereby heat gain through the North, East and West direction were lower compared to South orientation, therefore movable window shadings do not have much impact on North, East and West orientation. Thus, movable shading device with Venetian blinds was only applied to all southern windows of the building. The shading schedule as shown in Fig.8 was specified in TRNBuild of Type56.

5.1. Cooling Load Reduction with Movable shading device

The base case building energy consumption was simulated and compared after incorporating the movable shading device in all south bound windows to calculate the energy savings. The amount of energy savings were calculated from eqn.6.

$$Energy\ savings\ (\%) = \frac{Reduction\ in\ Energy\ Consumption\ for\ shading\ device}{Energy\ Consumption\ \ without\ shading\ device} \times 100\%$$

--------- (6)

Monthly energy saving percentage with the movable window shading device are illustrated in Fig.9.

The movable shading device showed the most efficient performance in the month of June when the solar irradiation and heat gain through window is quite high as depicted in Table 2 and Figs. 3&7. In the month of June the energy saving is maximum i.e. 14.9% though all other months of year it also shows a satisfactory performance as depicted in Fig. 9. Further the simulation has been extended to study the effect of movable shading device on the lighting energy consumption of this building. Then after incorporating the movable window shading device on the south oriented windows of this building and simulation program has been retrained with the same shading schedule as shown in Fig.8. From the Table 4 it is evident that the energy consumption reduced due to Space cool and Heat rejection by 18.7% and 16.4% respectively compared to base case simulation but no change in other areas of energy consumption including lighting. As the movable shading operates as per sun-path so the daylight harvesting from sun is not affected. This re-signified the importance of sun-path based automatic movable window shading device than the normal one.

5.2. Economic Analysis of Cooling Load Reduction and Movable shading device

Though from Fig.9 it is clear that movable shading device is technically viable for tropical climate because 9.8% energy consumption has been reduced annually but it is also required to test its financial viability. Therefore a detailed economic analysis also been carried out to find the financial viability of the proposed movable shading device.

There are almost 83 numbers of south oriented windows from third floor to ninth floor of the base-case building. In Table5 it is shown that the proposed sun-path based movable window shading device will reduce the overall energy costs by an estimated Rs. 19.5 Lakhs ($29,122) annually and to achieve the estimated savings an investment of approximately Rs.10 Lakhs ($14,950) is anticipated, resulting in a simple payback of 0.5 years.

6. Conclusion

The paper reviews various methodologies on tilted plane. Isotropic as well as Anisotropic index have been adopted in this study to estimate the global radiation (W/m^2) on any tilted plane. The solar radiation program algorithm was coded in FORTRAN77 compiler and validated with the measured solar irradiation data. The solar radiation can capable to measure solar radiation at any orientation of window pane. It was revealed that the southern part receives maximum radiation followed by east, west & north direction. Then the validated solar radiation program has been extended to find the total relative heat gain through the window pane. It was found that heat gain is more 96%, 38% and 20% respectively for south bound window, east and west bound window respect to northern window for a typical summer month. A validated TRNSYS 17 building model was generated to find the orientation effect on heat gain and thereby to recommend suitable solution for a building in tropical climate. Another Solar radiation simulation using Autodesk Ecotect was also carried out for base building to revalidate the finding of solar irradiation in different orientation which also reconfirms maximum irradiation happen southern window whereas northern window receives the least radiation in tropical climate. Based on the finding an automated experimentally designed movable exterior window shading device linked with sun path is optimally introduced for all 83 numbers of the south facing windows to reduce cooling load. The result shows that incorporation of movable shading device reduce the energy consumption of 9.8% annually, varies from 14.9% in typical summer month (June) and 4.5% in typical winter month (January). One interesting point also revealed that the energy consumption reduction happen only due to HVAC load i.e. for space cooling and heat rejection. The movable external shading operates as per sun-path so daylight harvesting from sun is not affected. This re-signified the importance of sun-path based automatic movable window shading device than a normal one. In order to check the financial viability of the proposed shading device an economic analysis also has been conducted which shows that the payback period is only 0.5 year. Therefore it can be concluded that the sun-path linked movable window shading device has a significant impact on the reduction of building energy consumption and south oriented windows of a building in tropical climate are the best choice to install this type of external shading device. After careful deliberation on the financial aspects of the movable shading device, it was brought to light by this study that the proposed exterior movable shading device linked with sun-path is economically viable even in small scale applications with a simple payback period of much less than a year.

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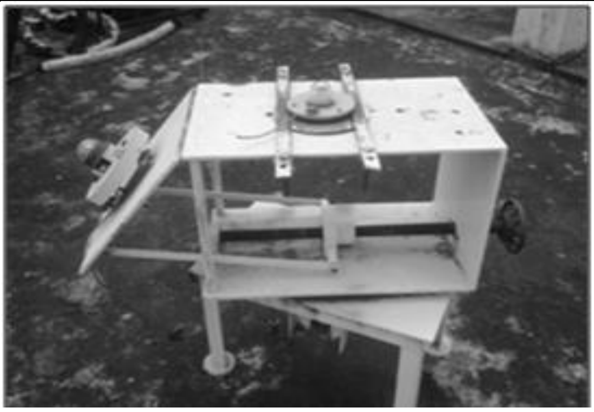


Fig.1 Solar Radiation Measurement Setup with Pyranometers on revolving platform for Horizontal, Vertical & other Inclined plane radiation

Fig. 2 Data-Logger connected with PC

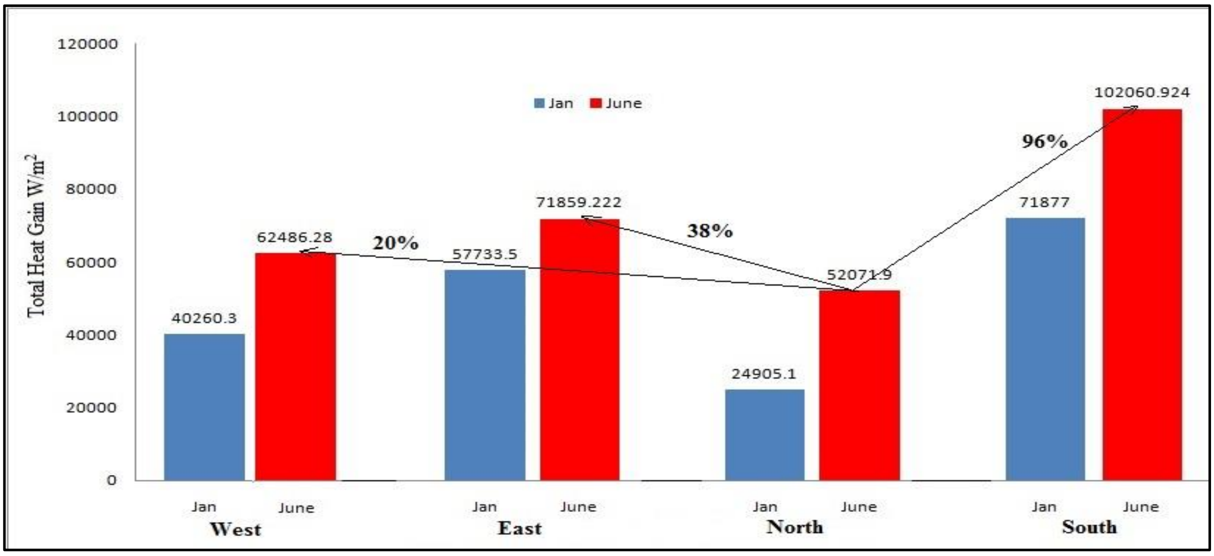


Fig.3. Heat gain inside the building through different oriented windows

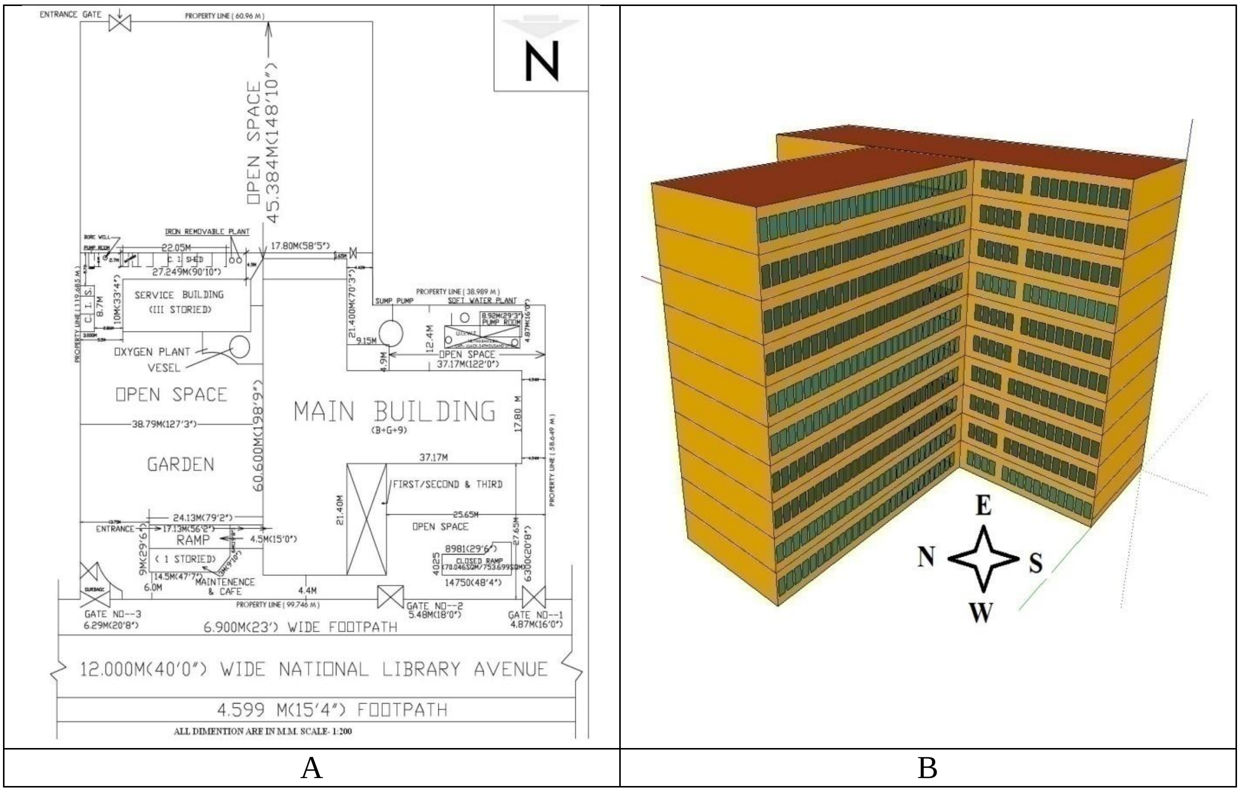


Fig5. (A) The building Floor plan and (B) 3-D model of the baseline house model

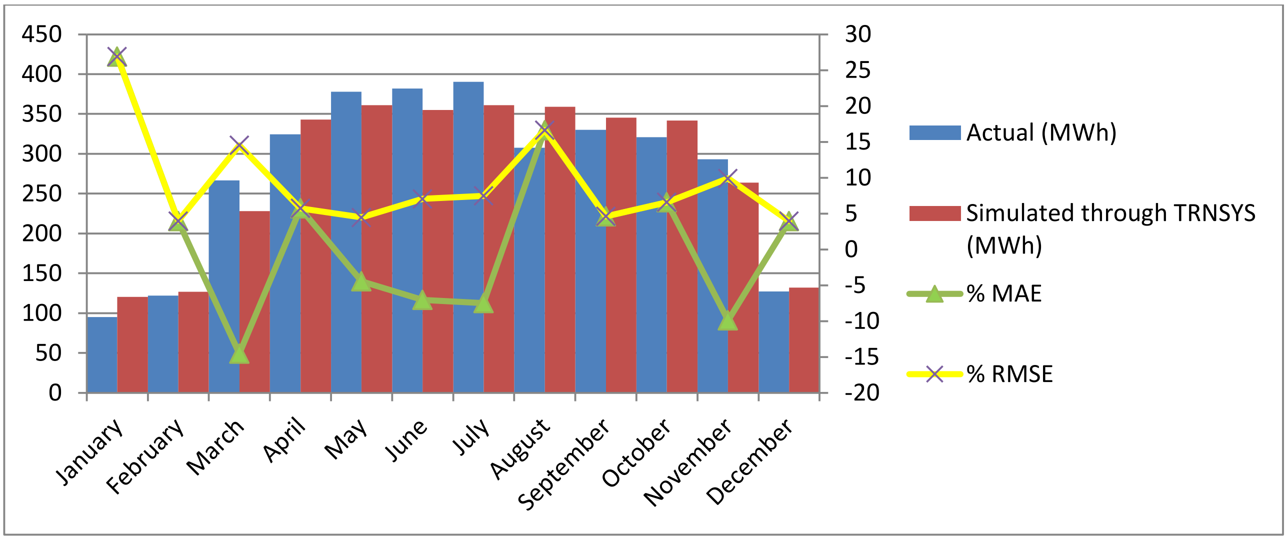


Fig.6 Actual and simulated monthly building energy consumption and results of statistical analysis

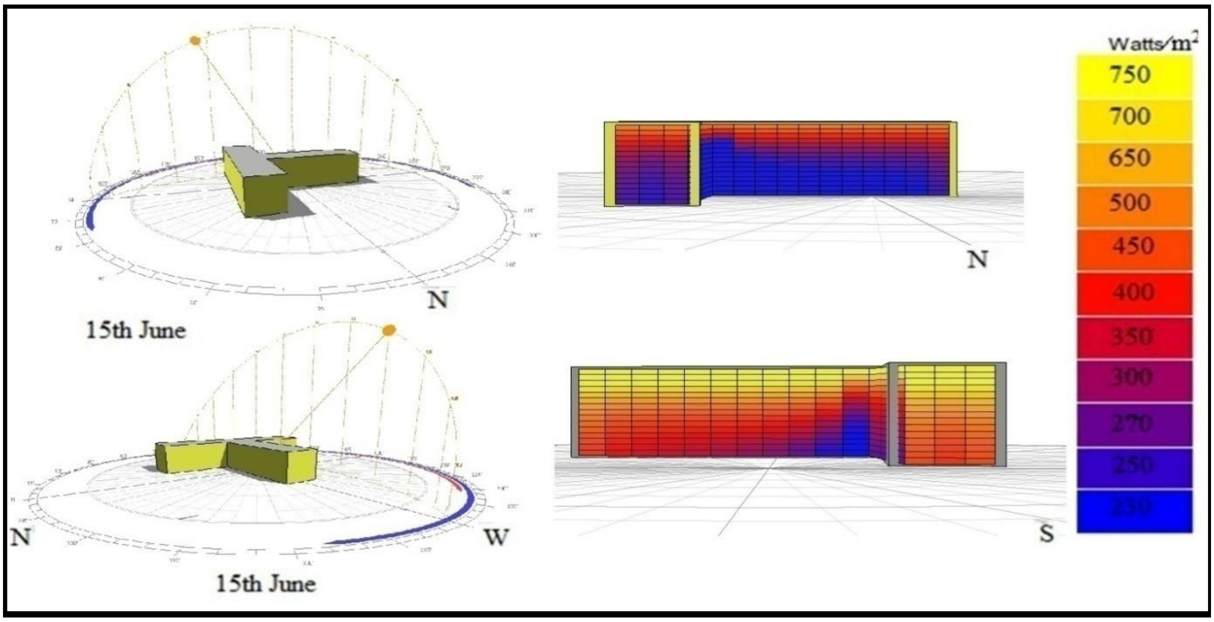


Fig.7 Solar radiation pattern analysis of Kothari Medical Centre building

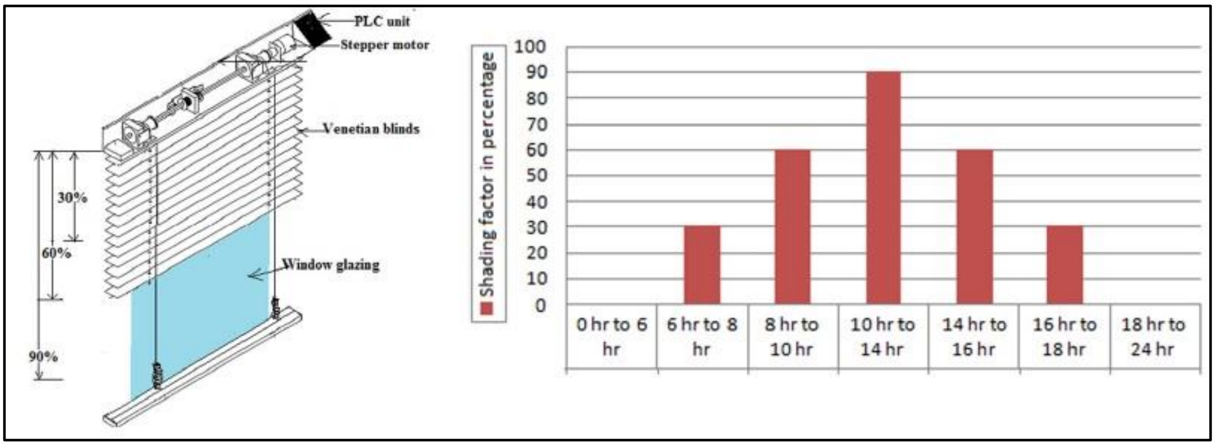


Fig.8. Movable shading device and Shading schedule [40]

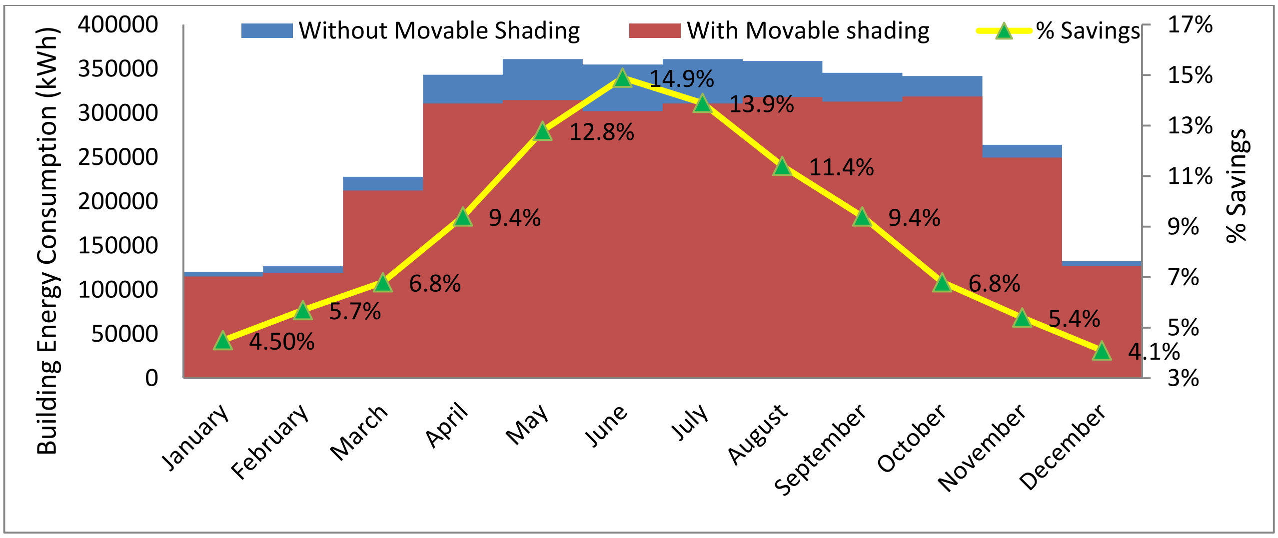


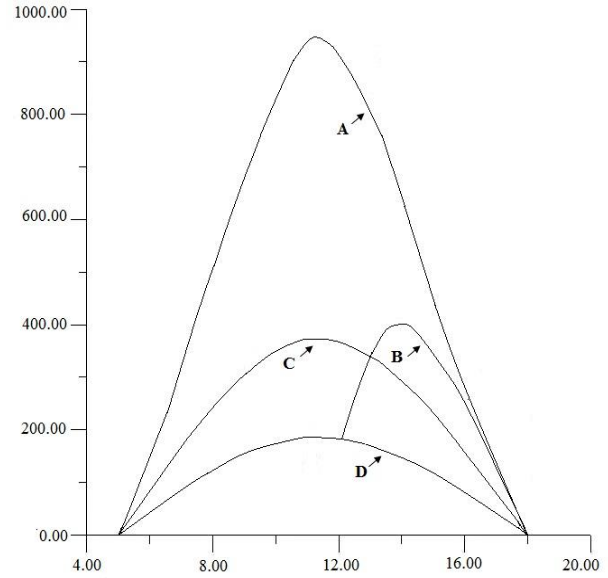
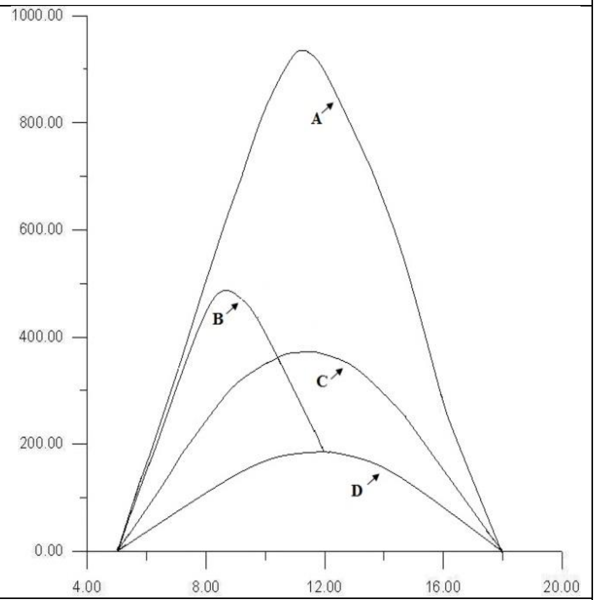
Fig.9. Monthly energy saving percentage with the movable window shading device

Table1. Various Solar Radiation models

Author	**Observation**	**Derived Relation**
Schulze, 1996[9]	Direct or solar Irradiance on horizontal surface	$E_{sh} = E_0 e^{-amTv}.\sin\gamma_s$
	Diffuse Irradiance on horizontal surface	$E_{dh} = 0.5E_0[q_a^m - e^{-amT_V}]\sin\gamma_s$
Angstrom,1924[10]	Monthly averaged Daily Radiation	$\frac{H}{H_{clear}} = \alpha + (1-\alpha)S$
Prescott,1940 [11]	Monthly averaged Daily Radiation	$\frac{H}{H_0} = a + bS$
Liu and Jorden,1960 [12]	Diffuse Irradiance on horizontal surface	$I_d = (0.271I_0 - 0.2939I_b)$
Hottel, 1976[13]	Direct Irradiance on horizontal surface	$I_b = I_0\left[a_0 + a_1 e^{\frac{k}{\cos\theta_z}}\right]$
Gueymard, 1993[14]	Irradiance at normal incident	$\frac{H_{b_n}}{H_{b_{nc}}} = \frac{s}{S_c}$
Viorel,1997 [15]	Global radiation	Global radiation at Clear sky and Cloudy sky was predicted based on the Pointed Cloudiness (PC).
Supit, 1998 [16]	Global radiation	$H = H_0\left[a\sqrt{(T_{max} - T_{min})}\right] + H_0\left[b\sqrt{1 - \frac{C_w}{8}}\right] + C$
Remund et al.,1998 [17]	Global radiation on tilted surface	Global radiation at different sky conditions are distinguished by Clearness Index (K_t).
Suehrcke, 2000 [18]	Time fraction of clear sky or time of sunshine duration	$f_{clear} = \left(\frac{H}{H_{clear}}\right)^2$
Helen, 2001 [19]	Clean sky beam Radiation	$\frac{H_b}{H_{bc}} = \frac{s}{S}$

Hay and Davies, 1980 [20]	Anisotropic Radiation	$I_T = (I_b + I_d A_i)R_b + I_d(1 - A_i)\left(\frac{1 + \cos\beta}{2}\right) + I\rho_g(\frac{1 - \cos\beta}{2})$

Table2. The patterns of solar radiation on different oriented window pane

<table>
<tr><td>June 15th</td><td></td></tr>
<tr><td>Simulation made at γ= +90° (West) and β = 90°</td><td>Simulation made at γ= - 90°(East) and β = 90°</td></tr>
<tr><td>
</td><td>
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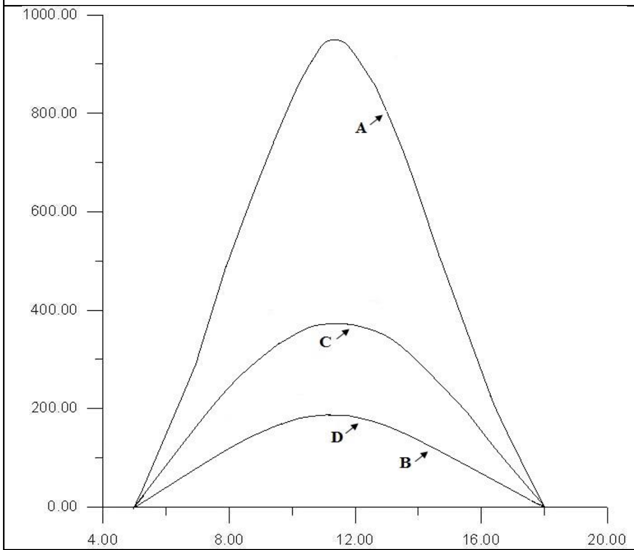
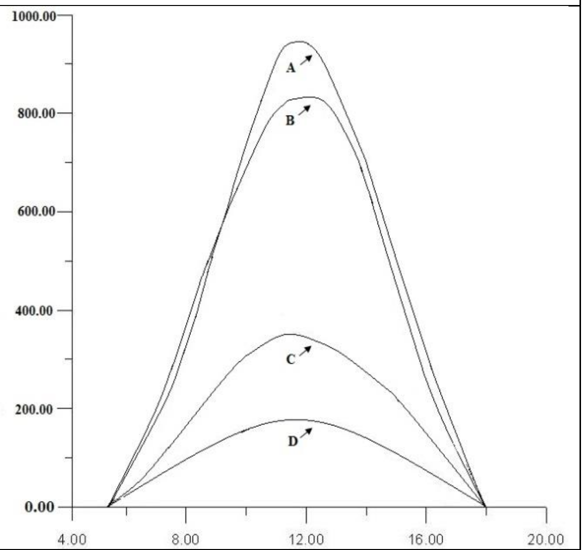
<tr><td>Simulation made at γ= 180°(North) and β = 90°</td><td>Simulation made at γ= 0°(South) and β = 90°</td></tr>
<tr><td>
</td><td>
</td></tr>
<tr><td>A = Total radiation at horizontal plane
B = Total radiation on inclined plane</td><td>C = Diffused radiation on horizontal plane
D = Diffused radiation on inclined plane</td></tr>
</table>

Table 3: The composition of different walls and their respective U-Values

Type	Material	Thickness(m)	U value(watt/meter²/K)
Ground Floor	Brick+Concrete+Floor	0.23	1.77
External Wall	Plaster+Brick+Plaster	0.29	3.25
Floor to ceiling	Plaster+Concrete+Floor	0.26	0.70
Roof	Plaster+Concrete+Insulation	0.19	1.93
Window	Single Glazed	0.006 (6 mm)	U=5.7W/m^2, SHGC=0.8

Table4: The zone wise area distribution and dimensions of doors & windows

Type of room(zone wise distribution)	**Area in m^2**	**% of total area**
Medical room + Patient room	7,456	36.5
Office + Dorm room	2,223	10.9
Lobby + Stair + Corridor + Vacant	6,178	30.2
Laboratory + Library	1,386	6.8
Storage	1,275	6.2
Toilet	374	1.8
Kitchen + Pantry + Dining + Laundry	821	4.0
Electrical room	718	3.5
Total	**20,431**	**100**

Fig4: Actual building layout (South side)

Window Dimensions			**Dimensions of Door**		
Window	Length	1.20 m	Door	Height	2.13m
	Breadth	0.24 m		Width	1.82m

Table5: Annual End-Use breakdown input by kWh

Annual Energy Consumption **(kWhX1000)**	**Space Cool**	**Heat Rejection**	Hot Water	Vent. Fans	Pumps & Aux.	Ext. Usage	Misc. Equip.	**Area Lights**	**Total**
Without Movable Shading	1,638.6	122.2	173.9	158.2	262	34.7	317.3	**629.9**	3,336.8
With Movable Shading Device	1,331.6	102.2	173.9	158.2	262	34.7	317.3	**629.9**	3,009.8
% Decrease in energy consumption (annual Average)	18.7%	16.4%	0%	0%	0%	0%	0%	**0%**	9.8%

Table:6 Cost Breakup of installation of Movable window shading device

	Total Number of Windows (South)		83	Windows per floor (4th to 9th Floor)- 14 Numbers
Investment	**Cost/Per Window**			INR(Rs)/ ($)
	Venetian Blind			3,500 ($52)
	Other Accessories			2,500 ($37)
	Motor+ PLC Module Price/Unit			25,300 ($378)
	Number of PLC+ Motor/Floor (Considered- 3 for 14 numbers of Windows)			18
		Total Cost	Movable Shading	9,53,400 ($14,238)
		Misc. Including labour	5% of total	47,670 ($112)
		Total Cost		1,001,070 ($14,950)
Saving		kWh Savings		327,000
		Cost Savings (@ Rs. 6/ kWh) ($0.09/kWh)		1,962,000 ($28,640)
			Payback Period	**0.5 Year**